BRITISH STANDARD

BS ISO 80000-12:2009

Quantities and units

Part 12: Solid state physics

ICS 01.060

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British Standards

National foreword

This British Standard is the UK implementation of ISO 80000-12:2009. It supersedes BS ISO 31-13:1992 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee SS/7, General metrology, quantities, units and symbols.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Contents

Page

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 80000-12 was prepared by Technical Committee ISO/TC 12, *Quantities and units,* in co-operation with IEC/TC 25, *Quantities and units, and their letter symbols*.

This first edition of ISO 80000-12 cancels and replaces ISO 31-13:1992. It also incorporates the Amendment ISO 31-13:1992/Amd.1:1998. The major technical changes from the previous standard are the following:

— the presentation of *numerical statements* has been changed;

— the *normative references* have been changed.

ISO 80000 consists of the following parts, under the general title *Quantities and units*:

— *Part 1: General*

— *Part 2: Mathematical signs and symbols to be used in the natural sciences and technology*

— *Part 3: Space and time*

— *Part 4: Mechanics*

— *Part 5: Thermodynamics*

— *Part 7: Light*

— *Part 8: Acoustics*

— *Part 9: Physical chemistry and molecular physics*

— *Part 10: Atomic and nuclear physics*

— *Part 11: Characteristic numbers*

— *Part 12: Solid state physics*

IEC 80000 consists of the following parts, under the general title *Quantities and units*:

— *Part 6: Electromagnetism*

— *Part 13: Information science and technology*

— *Part 14: Telebiometrics related to human physiology*

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Introduction

0.1 Arrangements of the tables

The tables of quantities and units in this International Standard are arranged so that the quantities are presented on the left-hand pages and the units on the corresponding right-hand pages.

All units between two full lines on the right-hand pages belong to the quantities between the corresponding full lines on the left-hand pages.

Where the numbering of an item has been changed in the revision of a part of ISO 31, the number in the preceding edition is shown in parenthesis on the left-hand page under the new number for the quantity; a dash is used to indicate that the item in question did not appear in the preceding edition.

0.2 Tables of quantities

The names in English and in French of the most important quantities within the field of this International Standard are given together with their symbols and, in most cases, their definitions. These names and symbols are recommendations. The definitions are given for identification of the quantities in the International System of Quantities (ISQ), listed on the left-hand pages of the table; they are not intended to be complete.

The scalar, vectorial or tensorial character of quantities is pointed out, especially when this is needed for the definitions.

In most cases only one name and only one symbol for the quantity are given; where two or more names or two or more symbols are given for one quantity and no special distinction is made, they are on an equal footing. When two types of italic letters exist (for example as with ϑ and θ; φ and ϕ; *a* and a; *g* and g), only one of these is given. This does not mean that the other is not equally acceptable. It is recommended that such variants should not be given different meanings. A symbol within parentheses implies that it is a reserve symbol, to be used when, in a particular context, the main symbol is in use with a different meaning.

In this English edition, the quantity names in French are printed in an italic font, and are preceded by *fr*. The gender of the French name is indicated by (m) for masculine and (f) for feminine, immediately after the noun in the French name.

0.3 Tables of units

0.3.1 General

The names of units for the corresponding quantities are given together with the international symbols and the definitions. These unit names are language-dependent, but the symbols are international and the same in all languages. For further information, see the SI Brochure (8th edition 2006) from BIPM and ISO 80000-1[1)].

The units are arranged in the following way:

a) The coherent SI units are given first. The SI units have been adopted by the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM). The use of coherent SI units,

1) To be published.

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and their decimal multiples and submultiples formed with the SI prefixes, are recommended, although the decimal multiples and submultiples are not explicitly mentioned.

b) Some non-SI units are then given, being those accepted by the International Committee for Weights and Measures (Comité International des Poids et Mesures, CIPM), or by the International Organization of Legal Metrology (Organisation Internationale de Métrologie Légale, OIML), or by ISO and IEC, for use with the SI.

   Such units are separated from the SI units in the item by use of a broken line between the SI units and the other units.

c) Non-SI units currently accepted by the CIPM for use with the SI are given in small print (smaller than the text size) in the "Conversion factors and remarks" column.

d) Non-SI units that are not recommended are given only in annexes in some parts of this International Standard. These annexes are informative, in the first place for the conversion factors, and are not integral parts of the standard. These deprecated units are arranged in two groups:

   1) units in the CGS system with special names;

   2) units based on the foot, pound, second, and some other related units.

e) Other non-SI units are given for information, especially regarding the conversion factors, in informative annexes in some parts of this International Standard.

0.3.2 Remark on units for quantities of dimension one, or dimensionless quantities

The coherent unit for any quantity of dimension one, also called a dimensionless quantity, is the number one, symbol 1. When the value of such a quantity is expressed, the unit symbol 1 is generally not written out explicitly.

EXAMPLE 1 Refractive index $n = 1{,}53 \times 1 = 1{,}53$

Prefixes shall not be used to form multiples or submultiples of this unit. Instead of prefixes, powers of 10 are recommended.

EXAMPLE 2 Reynolds number $Re = 1{,}32 \times 10^3$

Considering that plane angle is generally expressed as the ratio of two lengths and solid angle as the ratio of two areas, in 1995 the CGPM specified that, in the SI, the radian, symbol rad, and steradian, symbol sr, are dimensionless derived units. This implies that the quantities plane angle and solid angle are considered as derived quantities of dimension one. The units radian and steradian are thus equal to one; they may either be omitted, or they may be used in expressions for derived units to facilitate distinction between quantities of different kinds but having the same dimension.

0.4 Numerical statements in this International Standard

The sign $=$ is used to denote "is exactly equal to", the sign $\approx$ is used to denote "is approximately equal to", and the sign $:=$ is used to denote "is by definition equal to".

Numerical values of physical quantities that have been experimentally determined always have an associated measurement uncertainty. This uncertainty should always be specified. In this International Standard, the magnitude of the uncertainty is represented as in the following example.

EXAMPLE $l = 2{,}347\,82(32)$ m

In this example, $l = a(b)$ m, the numerical value of the uncertainty b indicated in parentheses is assumed to apply to the last (and least significant) digits of the numerical value a of the length l. This notation is used when b represents the standard uncertainty (estimated standard deviation) in the last digits of a. The numerical example given above may be interpreted to mean that the best estimate of the numerical value of the length l when l is expressed in the unit metre is 2,347 82, and that the unknown value of l is believed to lie between $(2{,}347\,82 - 0{,}000\,32)$ m and $(2{,}347\,82 + 0{,}000\,32)$ m with a probability determined by the standard uncertainty 0,000 32 m and the probability distribution of the values of l.

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Quantities and units —

Part 12:
Solid state physics

1 Scope

ISO 80000-12 gives names, symbols and definitions for quantities and units of solid state physics. Where appropriate, conversion factors are also given.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 80000-3:2006, *Quantities and units — Part 3: Space and time*

ISO 80000-4:2006, *Quantities and units — Part 4: Mechanics*

ISO 80000-5:2007, *Quantities and units — Part 5: Thermodynamics*

IEC 80000-6:2008, *Quantities and units — Part 6: Electromagnetism*

ISO 80000-8:2007, *Quantities and units — Part 8: Acoustics*

ISO 80000-9:2009, *Quantities and units — Part 9: Physical chemistry and molecular physics*

ISO 80000-10:—[2], *Quantities and units — Part 10: Atomic and nuclear physics*

3 Names, symbols, and definitions

The names, symbols, and definitions for quantities and units of solid state physics are given on the following pages.

2) To be published. (Revision of ISO 31-9:1992 and ISO 31-10:1992)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-1.1 (*13-1.1*)	lattice vector *fr vecteur* (m) *du réseau*	$\boldsymbol{R}$	translation vector that maps the crystal lattice on itself	
12-1.2 (*13-1.2*)	fundamental lattice vectors *fr vecteurs* (m) *de base*	$\boldsymbol{a}_1$, $\boldsymbol{a}_2$, $\boldsymbol{a}_3$, $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$	fundamental translation vectors for the crystal lattice	$\boldsymbol{R} = n_1\boldsymbol{a}_1 + n_2\boldsymbol{a}_2 + n_3\boldsymbol{a}_3$ where n_1, n_2, and n_3 are integers.
12-2.1 (*13-2.1*)	angular reciprocal lattice vector *fr vecteur* (m) *du réseau réciproque*	$\boldsymbol{G}$	vector whose scalar products with all fundamental lattice vectors are integral multiples of 2π	In crystallography, however, the quantity $\boldsymbol{G}/2\pi$ is sometimes used.
12-2.2 (*13-2.2*)	fundamental reciprocal lattice vectors *fr vecteurs* (m) *de base réciproques*	$\boldsymbol{b}_1$, $\boldsymbol{b}_2$, $\boldsymbol{b}_3$	fundamental translation vectors for the reciprocal lattice	$\boldsymbol{a}_i \cdot \boldsymbol{b}_i = 2\pi\delta_{ij}$ In crystallography, however, the quantities $\boldsymbol{b}_j/(2\pi)$ are also often used.
12-3 (*13-3*)	lattice plane spacing *fr espacement* (m) *entre plans réticulaires*	d	distance between successive lattice planes	
12-4 (*13-4*)	Bragg angle *fr angle* (m) *de Bragg*	ϑ	$2d \sin \vartheta = n\lambda$ where d is the lattice plane spacing (item 12-3), λ is the wavelength (ISO 80000-7:2008, item 7-3) of the radiation, and n is an integer	
12-5 (*13-5*)	order of reflexion *fr ordre* (m) *de réflexion*	n		

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-1.a	metre	m		ångström (Å), 1 Å $= 10^{-10}$ m
12-2.a	metre to the power minus one	m^{-1}		
12-3.a	metre	m		ångström (Å), 1 Å $= 10^{-10}$ m
12-4.a	radian	rad		
12-4.b	degree	°		$1° = (\pi/180)$ rad $\approx$ 0,017 453 29 rad
12-5.a	one	1		See the Introduction, 0.3.2.

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-6.1 (*13-6.1*)	short-range order parameter *fr paramètre* (m) *d'ordre local*	r, σ	fraction of nearest-neighbour atom pairs in an Ising ferromagnet having magnetic moments in one direction, minus the fraction having magnetic moments in the opposite direction	Similar definitions apply to other order-disorder phenomena. Other symbols are frequently used.
12-6.2 (*13-6.2*)	long-range order parameter *fr paramètre* (m) *d'ordre à grande distance*	R, s	fraction of atoms in an Ising ferromagnet having magnetic moments in one direction, minus the fraction having magnetic moments in the opposite direction	
12-6.3 (—)	atomic scattering factor *fr facteur* (f) *de diffusion atomique*	f	$f = E_\mathrm{a}/E_\mathrm{e}$ where E_a is the radiation amplitude scattered by the atom and E_e is the radiation amplitude scattered by a single electron	
12-6.4 (—)	structure factor *fr facteur* (f) *de structure*	$F(h, k, l)$	$F(h,\ k,\ l) = \sum_{n=1}^{N} f_n \exp[2\pi \mathrm{i}(hx_n + ky_n + lz_n)]$ where f_n is the atomic scattering factor (item 12.6.3) for atom n, and x_n, y_n, z_n are fractional coordinates in the unit cell; for h, k, l, see Annex A	
12-7 (*13-7*)	Burgers vector *fr vecteur* (m) *de Burgers*	$\boldsymbol{b}$	vector characterizing a dislocation, i.e. the closing vector in a Burgers circuit encircling a dislocation line	

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**Inter-national symbol**	**Definition**	**Conversion factors and remarks**
12-6.a	one	1		See Introduction, 0.3.2.
12-7.a	metre	m		

(*continued*)

SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-8.1 (*13-8.1*)	particle position vector *fr rayon* (m) *vecteur d'une particule*	$\boldsymbol{r}$, $\boldsymbol{R}$	$\boldsymbol{r}$ is the position vector (ISO 80000-3:2006, item 3-1.11) of a particle	Often, $\boldsymbol{r}$ is used for electrons and $\boldsymbol{R}$ is used for atoms and other heavier particles.
12-8.2 (*13-8.2*)	equilibrium position vector of an ion or an atom *fr rayon* (m) *vecteur d'équilibre d'un ion ou d'un atome*	$\boldsymbol{R}_0$	$\boldsymbol{R}_0$ is the position vector (ISO 80000-3:2006, item 3-1.11) of a particle in equilibrium	
12-8.3 (*13-8.3*)	displacement vector of ion or atom *fr vecteur* (m) *de déplacement d'un ion ou d'un atome*	$\boldsymbol{u}$	$\boldsymbol{u} = \boldsymbol{R} - \boldsymbol{R}_0$ $\boldsymbol{R}$ is the particle position vector (item 12-8.1) and $\boldsymbol{R}_0$ is the equilibrium position vector of a particle (item 12-8.2)	
12-9 (*13-9*)	Debye-Waller factor *fr facteur* (m) *de Debye-Waller*	D, B	factor by which the intensity of a diffraction line is reduced because of the lattice vibrations	D is sometimes expressed as $D = \exp(-2W)$; in Mössbauer spectroscopy, it is also called the f factor and denoted by f.

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-8.a	metre	m		
12-9.a	one	1		See Introduction, 0.3.2.

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-10.1 (*13-10.1*)	angular wavenumber, angular repetency *fr nombre* (m) *d'onde angulaire*	k, (q)	$k = p/\hbar$ where p is the linear momentum (ISO 80000-4:2006, item 4-8) of quasi free electrons in an electron gas and $\hbar$ is the Planck constant h (ISO 80000-10:—, item 10-6.1), divided by 2π; for phonons, its magnitude is $k = 2\pi/\lambda$ where λ is the wavelength (ISO 80000-3:2006, item 3-17) of the lattice vibrations	The corresponding vector quantity $\boldsymbol{k}$ or $\boldsymbol{q}$ is called the wave vector. When a distinction is needed between k and the symbol for the Boltzmann constant, k_B can be used for the latter. When a distinction is needed, q should be used for phonons, and k for particles such as electrons and neutrons.
12-10.2 (*13-10.2*)	Fermi angular wavenumber, Fermi angular repetency *fr nombre* (m) *d'onde angulaire de Fermi*	k_F	angular wavenumber (item 12-10.1) of electrons in states on the Fermi sphere	The method of cut-off shall be specified. In solid state physics, angular wavenumber is often called wavenumber.
12-10.3 (*13-10.3*)	Debye angular wavenumber, Debye angular repetency *fr nombre* (m) *d'onde angulaire de Debye*	q_D	cut-off angular wavenumber (item 12-10.1) in the Debye model of the vibrational spectrum of a solid	
12-11 (*13-11*)	Debye angular frequency *fr pulsation* (f) *de Debye*	ω_D	cut-off angular frequency (ISO 80000-3:2006, item 3-16) in the Debye model of the vibrational spectrum of a solid	The method of cut-off shall be specified.
12-12 (*13-12*)	Debye temperature *fr température* (f) *de Debye*	Θ_D	$\Theta_\text{D} = \hbar\,\omega_\text{D}/k$ where k is the Boltzmann constant (ISO 80000-9:2009, item 9-43), $\hbar$ is the Planck constant h (ISO 80000-10:—, item 10-6.1), divided by 2π, and ω_D is the Debye angular frequency (item 12-11)	$k =$ 1,380 650 4(24) $\times 10^{-23}$ J/K [CODATA 2006] $\hbar =$ 1,054 571 628(53) $\times 10^{-34}$ J · s [CODATA 2006]

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-10.a	radian per metre	rad/m		
12-10.b	metre to the power minus one	m^{-1}		
12-11.a	radian per second	rad/s		
12-11.b	second to the power minus one	s^{-1}		
12-12.a	kelvin	K		

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-13 (*13-13*)	density of states (in terms of angular frequency) *fr concentration* (f) *spectrale des modes de vibration* (*en fonction de la pulsation*), *densité* (f) *des modes*	g	number of vibrational modes in an infinitesimal interval of angular frequency (ISO 80000-3:2006, item 3-16), divided by the range of that interval and by volume (ISO 80000-3:2006, item 3-4)	$g(\omega) = \dfrac{\mathrm{d}N(\omega)}{\mathrm{d}\omega}$ where $N(\omega)$ is the total number of vibrational modes with angular frequency less than ω, divided by volume.
12-14 (*13-14*)	Grüneisen parameter *fr paramètre* (m) *de Grüneisen*	γ, ($\mathit{\Gamma}$)	$\gamma = \alpha_V / (\varkappa_T c_V \rho)$ where α_V is cubic expansion coefficient (ISO 80000-5:2007, item 5-3.2), $\varkappa_T$ is isothermal compressibility (ISO 80000-5:2007, item 5-5.1), c_V is specific heat capacity at constant volume (ISO 80000-5:2007, item 5-16.3), and ρ is mass density (ISO 80000-4:2006, item 4-2)	
12-15 (*13-15*)	Madelung constant *fr constante* (f) *de Madelung*	α, A	for a uni-univalent ionic crystal of specified structure, the binding energy V_b (ISO 80000-4:2006, item 4-27.2) per pair of ions is $V_\mathrm{b} = \alpha \dfrac{e^2}{4\pi\varepsilon_0 a}$ where e is the elementary charge (ISO 80000-9:2009, item 9-43), ε_0 is the electric constant (IEC 80000-6:2008, item 6-14.1), and a is a lattice constant which should be specified	Uni-univalent ionic crystals basically consist of single-charged ions like Na^+Cl^-. The binding energy mainly results from Coulomb force. In most cases, a is close to the lattice plane spacing, d (item 12-3).

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UNITS				SOLID STATE PHYSICS
Item No.	Name	International symbol	Definition	Conversion factors and remarks
12-13.a	second per radian cubic metre	$s/(rad \cdot m^3)$		
12-14.a	one	1		See Introduction, 0.3.2.
12-15.a	one	1		See Introduction, 0.3.2.

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-16.1 (*13-16.1*)	mean free path of phonons *fr libre parcours* (m) *moyen des phonons*	l_{ph}, (Λ)	mean free path (ISO 80000-10:—, item 10-73) of phonons	
12-16.2 (*13-16.2*)	mean free path of electrons *fr libre parcours* (m) *moyen des électrons*	l_{e}, (l)	mean free path (ISO 80000-10:—, item 10-73) of electrons	
12-17 (*13-17*)	energy density of states *fr densité* (f) *des états d'énergie, densité* (f) *des états*	n_E, ρ	$\rho(E) = n_E(E) = \frac{\mathrm{d}N(E)}{\mathrm{d}E}\frac{1}{V}$ where $N(E)$ is the total number of states with energy less than E (ISO 80000-4:2006, item 4-27.4), and V is volume (ISO 80000-3:2006, item 3-4)	Density of states refers to electrons or other entities, e.g. phonons. It can, for example, refer to amount of substance instead of volume.
12-18 (*13-18*)	residual resistivity *fr résistivité* (f) *résiduelle*	ρ_{R}	for metals, resisitivity (IEC 80000-6:2008, item 6-44) extrapolated to zero thermodynamic temperature (ISO 80000-5:2007, item 5-1)	
12-19 (*13-19*)	Lorenz coefficient *fr coefficient* (m) *de Lorenz*	L	$L = \lambda/(\sigma T)$ where λ is thermal conductivity (ISO 80000-5:2007, item 5-9), σ is electric conductivity (IEC 80000-6:2008, item 6-43), and T is thermodynamic temperature (ISO 80000-5:2007, item 5-1)	

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-16.a	metre	m		
12-17.a	joule to the power minus one per cubic metre	J^{-1}/m^3		
12-17.b	electronvolt to the power minus one per cubic metre	eV^{-1}/m^3		$1\ eV^{-1}/m^3 =$ $6{,}241\ 509\ 65(16) \times 10^{18}\ J^{-1}/m^3$
12-18.a	ohm metre	$\Omega \cdot m$		
12-19.a	volt squared per kelvin squared	V^2/K^2		

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-20 (*13-20*)	Hall coefficient *fr coefficient* (m) *de Hall*	R_{H}, A_{H}	in an isotropic conductor, relation between electric field strength, $\boldsymbol{E}$, (IEC 80000-6:2008, item 6-10) and electric current density, $\boldsymbol{J}$, (IEC 80000-6:2008, item 6-8) is $\boldsymbol{E} = \rho \boldsymbol{J} + R_{\mathrm{H}}(\boldsymbol{B} \times \boldsymbol{J})$ where ρ is resistivity (IEC 80000-6:2008, item 6-44) and $\boldsymbol{B}$ is magnetic flux density (IEC 80000-6:2008, item 6-21)	
12-21 (*13-21*)	source voltage between substances a and b *fr tension* (f) *de source entre substances a et b*	E_{ab}	source voltage (IEC 80000-6:2008, item 6-36) between substances a and b	E_{ab} is positive if the potential V_{a} is higher than V_{b} at the cold junction.
12-22 (*13-22*)	Seebeck coefficient for substances a and b *fr coefficient* (m) *de Seebeck pour les substances a et b*	S_{ab}, ($\varepsilon_{\mathrm{ab}}$)	$S_{\mathrm{ab}} = \frac{\mathrm{d}E_{\mathrm{ab}}}{\mathrm{d}T}$ where E_{ab} is the thermosource voltage between substances a and b (item 12-21) and T is the thermodynamic temperature (ISO 80000-5:2007, item 5-1) of the hot junction	$S_{\mathrm{ab}} = S_{\mathrm{a}} - S_{\mathrm{b}}$ where S_{a} is the Seebeck coefficient for substance a.
12-23 (*13-23*)	Peltier coefficient for substances a and b *fr coefficient* (m) *de Peltier pour les substances a et b*	Π_{ab}	Peltier heat power developed at a junction, divided by the electric current (IEC 80000-6:2008, item 6-1) flowing from substance a to substance b	$\Pi_{\mathrm{ab}} = \Pi_{\mathrm{a}} - \Pi_{\mathrm{b}}$ where Π_{a} is the Peltier coefficient for substance a.
12-24 (*13-24*)	Thomson coefficient *fr coefficient* (m) *de Thomson*	μ, (τ)	Thomson heat power developed, divided by the electric current (IEC 80000-6:2008, item 6-1) and the temperature (ISO 80000-5:2007, item 5-1) difference	μ is positive if heat is developed when the temperature decreases in the direction of the electric current.

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-20.a	cubic metre per coulomb	m^3/C		
12-21.a	volt	V		
12-22.a	volt per kelvin	V/K		
12-23.a	volt	V		
12-24.a	volt per kelvin	V/K		

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-25.1 (—)	energy level *fr niveau* (m) *d'énergie*	E	ionization energy for an electron at the Fermi energy (item 12-28.1) in the interior of a substance	Quantum state energy mainly results from Coulomb force. The term "energy level" is often used for the state of the electron, not only for its energy. The contact potential difference between substances a and b is given by $V_\mathrm{a} - V_\mathrm{b} = (\Phi_\mathrm{a} - \Phi_\mathrm{b})/e$ where e is the elementary charge (ISO 80000-9:2009, item 9-43). A set of energy levels in which the energies occupy an interval practically continuously is called an energy band.
12-25.2 (*13-25*)	work function *fr travail* (m) *d'extraction*	Φ	energy (ISO 80000-4:2006, item 4-27.4) difference between an electron at rest at infinity and an electron at a certain energy level (12-25.1)	
12-25.3 (—)	ionization energy *fr énergie* (f) *d'ionisation*	E_i	energy (ISO 80000-4:2006, item 4-27.4) difference between an electron at rest at infinity and an electron at a certain energy level (item 12-25.1)	
12-26 (*13-26*)	electron affinity *fr affinité* (f) *électronique*	χ	energy (ISO 80000-4:2006, item 4-27.4) difference between an electron at rest at infinity and an electron at the lowest level of the conduction band in an insulator or semiconductor	
12-27 (*13-27*)	Richardson constant *fr facteur* (m) *de Richardson*	A	the thermionic emission current density, J, (IEC 80000-6:2008, item 6-8) for a metal is $J = AT^2 \exp(-\Phi/kT)$ where T is thermodynamic temperature (ISO 80000-5:2007, item 5-1), k is the Boltzmann constant (ISO 80000-9:2009, item 9-43), and Φ is a work function (item 12-25.2)	

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UNITS				**SOLID STATE PHYSICS**
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-25.a	joule	J		
12-25.b	electronvolt	eV	1 eV $:= e \cdot 1$ V where e is the elementary charge (ISO 80000-9:2009, item 9-43)	1 eV $=$ 1,602 176 487(40) $\times$ 10^{-19} J [CODATA 2006]
12-26.a	joule	J		
12-26.b	electronvolt	eV	1 eV $:= e \cdot 1$ V where e is the elementary charge (ISO 80000-9:2009, item 9-43)	1 eV $=$ 1,602 176 487(40) $\times$ 10^{-19} J [CODATA 2006]
12-27.a	ampere per square metre kelvin squared	$A/(m^2 \cdot K^2)$		

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-28.1 (*13-28.1*)	Fermi energy *fr énergie* (f) *de Fermi*	E_F	in a metal, highest occupied energy level (item 12-25.1) at zero thermodynamic temperature (ISO 80000-5:2007, item 5-1)	At $T = 0$, E_F is equal to the chemical potential per electron.
12-28.2 (*13-28.2*)	gap energy *fr largeur* (f) *de bande interdite, écart* (m) *énergétique*	E_g	difference in energy (ISO 80000-4:2006, item 4-27.4) between the lowest level of conduction band and the highest level of valence band	
12-28.3 (*13-28.3*)	donor ionization energy *fr énergie* (f) *d'ionisation de donneur*	E_d	ionization energy (item 12-25.3) of a donor	
12-28.4 (*13-28.4*)	acceptor ionization energy *fr énergie* (f) *d'ionisation d'accepteur*	E_a	ionization energy (item 12-25.3) of an acceptor	
12-29 (*13-29*)	Fermi temperature *fr température* (f) *de Fermi*	T_F	$T_\mathrm{F} = E_\mathrm{F}/k$ where E_F is Fermi energy (item 12.28.1) and k is the Boltzmann constant (ISO 80000-9:2009, item 9-43)	

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-28.a	joule	J		
12-28.b	electronvolt	eV	1 eV $:= e \cdot 1$ V where e is the elementary charge (ISO 80000-9:2009, item 9-43)	1 eV $=$ 1,602 176 487(40) $\times$ 10^{-19} J [CODATA 2006]
12-29.a	kelvin	K		

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-30.1 (*13-30.1*)	electron density, electron number per volume *fr nombre* (m) *volumique électronique, densité* (f) *électronique*	n	number of electrons per volume in conduction band	Subscripts n and p or $-$ and $+$ are often used to denote electrons and holes, respectively. n_n and n_p are also used for electron number densities, and p_n and p_p for hole number densities, in n-type and p-type regions, respectively, of an n-p junction.
12-30.2 (*13-30.2*)	hole density, hole number per volume *fr nombre* (m) *volumique de trous, densité* (f) *de trous*	p	number of holes per volume in valence band	
12-30.3 (*13-30.31*)	intrinsic carrier density, intrinsic number per volume *fr nombre* (m) *volumique intrinsèque, densité* (f) *intrinsèque*	n_i	$np = n_\mathrm{i}^2$ where n is electron density (item 12-30.1), and p is hole density (item 12-30-2)	
12-30.4 (*13-30.4*)	donor density, donor number per volume *fr nombre* (m) *volumique de donneurs, densité* (f) *de donneurs*	n_d	number per volume of donor levels	
12-30.5 (*13-30.5*)	acceptor density, acceptor number per volume *fr nombre* (m) *volumique d'accepteurs, densité* (f) *d'accepteurs*	n_a	number per volume of acceptor levels	

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UNITS				**SOLID STATE PHYSICS**
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-30.a	metre to the power minus three	m^{-3}		

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-31 (*13-31*)	effective mass *fr masse* (f) *effective*	m^*	effective mass is used in the motional equation for electrons in solid state bodies, depending on the wavenumber, k, corresponding to its velocity and energy level $m^* = \hbar^2 k(\mathrm{d}\varepsilon/\mathrm{d}k)$ where ε is the energy of the electron	In semiconductors, m_n^* is used for electrons, and m_p^* for holes. m^* is usually larger than electron mass.
12-32 (*13-32*)	mobility ratio *fr rapport* (m) *de mobilité*	b	$b = \mu_\mathrm{n}/\mu_\mathrm{p}$ where μ_n and μ_p are mobilities (ISO 80000-10:—, item 10-63) for electrons and holes, respectively	
12-33.1 (*13-33.1*)	relaxation time *fr temps* (m) *de relaxation*	τ	time constant (ISO 80000-3:2006, item 3-13) for exponential decay towards equilibrium	For electrons in metals, $\tau = l/v_\mathrm{F}$ where l is the mean free path and v_F is the speed of electrons on the Fermi sphere.
12-33.2 (*13-33.2*)	carrier lifetime *fr durée* (f) *de vie des porteurs*	τ, τ_n, τ_p	time constant (ISO 80000-3:2006, item 3-13) for recombination or trapping of minority charge carriers in semiconductors	
12-34 (*13-34*)	diffusion length *fr longueur* (f) *de diffusion*	L, L_n, L_p	$L = \sqrt{D\tau}$ where D is the diffusion coefficient (ISO 80000-9:2009, item 9-45) and τ is lifetime (ISO 80000-3:2006, item 3-7)	
12-35 (*13-35*)	exchange integral *fr intégrale* (f) *d'échange*	K	constituent of the interaction energy (ISO 80000-4:2006, item 4-27.4) between the spins of adjacent electrons in matter arising from the overlap of electron state functions	The Coulomb integral is denoted J.

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UNITS				**SOLID STATE PHYSICS**
Item No.	**Name**	**Inter-national symbol**	**Definition**	**Conversion factors and remarks**
12-31.a	kilogram	kg		
12-32.a	one	1		See Introduction, 0.3.2.
12-33.a	second	s		
12-34.a	metre	m		
12-35.a	joule	J		
12-35.b	electronvolt	eV	1 eV $:= e \cdot$ 1 V where e is the elementary charge (ISO 80000-9:2009, item 9-43)	1 eV $=$ 1,602 176 487(40) $\times$ 10^{-19} J [CODATA 2006]

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-36.1 (*13-36.1*)	Curie temperature *fr température* (f) *de Curie*	T_C	critical thermodynamic temperature (ISO 80000-5:2007, item 5-1) of a ferromagnet	T_cr is used for critical thermodynamic temperature in general.
12-36.2 (*13-36.2*)	Néel temperature *fr température* (f) *de Néel*	T_N	critical thermodynamic temperature (ISO 80000-5:2007, item 5-1) of an antiferromagnet	
12-36.3 (*13-36.3*)	superconduction transition temperature *fr température* (f) *de transition supra-conductrice*	T_c	critical thermodynamic temperature (ISO 80000-5:2007, item 5-1) of a superconductor	
12-37.1 (*13-37.1*)	thermodynamic critical magnetic flux density *fr induction* (f) *magnétique critique thermo-dynamique*	B_c	$G_\mathrm{n} - G_\mathrm{s} = \frac{1}{2} \frac{B_\mathrm{c}^2 \cdot V}{\mu_0}$ where G_n and G_s are the Gibbs energies (ISO 80000-5:2007, item 5-20.5) at zero magnetic flux density (IEC 80000-6:2008, item 6-21) in a normal conductor and superconductor, respectively, μ_0 is the magnetic constant (IEC 80000-6, item 6-26.1), and V is volume (ISO 80000-3:2006, item 3-4)	In type I superconductors, B_c is the critical magnetic flux density for disappearance of superconductivity. The symbol B_c3 is used for the critical magnetic flux density for disappearance of surface superconductivity.
12-37.2 (*13-37.2*)	lower critical magnetic flux density *fr induction* (f) *magnétique critique inférieure*	B_c1	for type II superconductors, threshold magnetic flux density (IEC 80000-6:2008, item 6-21) for magnetic flux (IEC 80000-6:2008, item 6-22.1) entering the superconductor	
12-37.3 (*13-37.3*)	upper critical magnetic flux density *fr induction* (f) *magnétique critique supérieure*	B_c2	for type II superconductors, threshold magnetic flux density (IEC 80000-6:2008, item 6-21) for disappearance of bulk superconductivity	

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**Inter-national symbol**	**Definition**	**Conversion factors and remarks**
12-36.a	kelvin	K		
12-37.a	tesla	T	1 T := 1 Wb/m^2	For weber, Wb, see item 12-41.a.

(*continued*)

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SOLID STATE PHYSICS				**QUANTITIES**
Item No.	**Name**	**Symbol**	**Definition**	**Remarks**
12-38 (*13-38*)	superconductor energy gap *fr largeur* (f) *de bande interdite d'un supra-conducteur*	Δ	width of the forbidden energy (ISO 80000-5:2007, item 5-20.1) band in a superconductor	
12-39.1 (*13-39.1*)	London penetration depth *fr profondeur* (f) *de pénétration de London*	λ_{L}	if an applied magnetic field is parallel to the plane surface of a semi-infinite superconductor, the field penetrates the superconductor according to the expression $B(x) = B(0)\ \exp(-x/\lambda_{\mathrm{L}})$ where B is magnetic flux density (IEC 80000-6:2008, item 6-21) and x is the distance (ISO 80000-3:2006, item 3-1.9) from the surface	
12-39.2 (*13-39.2*)	coherence length *fr longueur* (f) *de cohérence*	ξ	distance (ISO 80000-3:2006, item 3-1.9) in a superconductor over which the effect of a perturbation is appreciable	
12-40 (*13-40*)	Landau-Ginzburg number *fr nombre* (m) *de Landau-Ginzburg*	κ	at zero thermodynamic temperature (ISO 80000-5:2007, item 5-1) $\kappa = \lambda_{\mathrm{L}}/(\xi\sqrt{2})$ where λ_{L} is London penetration depth (item 12-39.1) and ξ is coherence length (item 12-39.2)	
12-41 (*13-41*)	magnetic flux quantum *fr quantum* (m) *de flux magnétique*	Φ_0	$\Phi_0 = h/2e$ where h is the Planck constant (ISO 80000-10:—, item 10-6.1) and e is the elementary charge (ISO 80000-10:—, item 10-5.1)	$\Phi_0 = 2{,}067\ 833\ 667(52) \times 10^{-15}$ Wb [CODATA 2006]
12-42 (—)	Josephson constant *fr constante* (f) *de Josephson*	K_{J}	$K_{\mathrm{J}} = 1/\Phi_0$ where Φ_0 is magnetic flux quantum (item 12-41)	$K_{\mathrm{J}} = 483\ 597{,}891(12) \times 10^9$ Hz V^{-1} [CODATA 2006]

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UNITS				SOLID STATE PHYSICS
Item No.	**Name**	**International symbol**	**Definition**	**Conversion factors and remarks**
12-38.a	joule	J		
12-38.b	electronvolt	eV	1 eV $:= e \cdot 1$ V where e is the elementary charge (ISO 80000-9:2009, item 9-43)	1 eV $=$ 1,602 176 487(40) $\times$ 10^{-19} J [CODATA 2006]
12-39.a	metre	m		
12-40.a	one	1		See Introduction, 0.3.2.
12-41.a	weber	Wb	1 Wb $:=$ 1 V $\cdot$ s	
12-42.a	weber to the power minus one	Wb^{-1}		

(*concluded*)

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Annex A
(normative)

Symbols for planes and directions in crystals

Miller indices	h_1, h_2, h_3 or h, k, l
Single plane or set of parallel planes in lattice	(h_1, h_2, h_3) or (h, k, l)
Full set of planes in lattice equivalent by symmetry	$\begin{Bmatrix} h_1 \\ h_2 \\ h_3 \end{Bmatrix}$ or $\begin{Bmatrix} h \\ k \\ l \end{Bmatrix}$
	$\{h_1, h_2, h_3\}$ or $\{h, k, l\}$
Direction in lattice	$[u, v, w]$
Full set of directions in lattice equivalent by symmetry	$\langle u, v, w \rangle$

NOTE 1 If the letter symbols are replaced by numbers in the bracketed expressions, it is customary to omit the commas.

NOTE 2 A negative numerical value of h, k, or l is commonly indicated by a bar above the number, for example $(\bar{1}10)$.

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[1] CODATA 2006, http://physics.nist.gov/cuu/Constants/

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